Codes and Standards Analysis

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Objectives

- Task A - Determine how close an ignition source must be to a hydrogen leak to cause ignition of the leak. Compare that distance to the positions of 4.0% hydrogen (upward propagating lean limit of combustion).
- Task B - Determine characteristics of ignition of lean mixtures of hydrogen and air flowing in ducts. Determine the effects of the Reynolds number and any other important parameters.
- Task C - Determine the grounding needs of electrolyzers or fuel cells for use in residential garages.
- Task D - Determine hazards produced by electrical shorts in conjunction with portable fuel cells.

Budget

- Total funding for the project $141,485
- DOE share $111,352
- Contractor share $30,133
- Funding in FY03 $141,485

Technical Barriers and Targets

- DOE Technical Barriers for Hydrogen Codes and Standards
  - N. Lack of Technical Data to Revise NFPA 55 Standard (for underground and aboveground storage).
  - P. Current Large Footprint Requirements for Hydrogen Fueling Stations.
- DOE Technical Target
  - 7) Incorporate new analysis and data into revised standard. (Objective 2, Task 6)

Approach

- Task A - Construct experimental leak apparatus to allow measurement of hydrogen concentration in the plume created by the leak. Construct CFD model of leak. Compare CFD model to experimental and measured values of hydrogen concentration. Determine distance farthest away from leak that the plume can be ignited, by trial ignitions. Compare distance to position of 4% hydrogen concentration. Compare to homogeneous quiescent hydrogen ignition behavior.

- Task B - construct experimental duct apparatus to allow attempted ignitions of homogeneous lean hydrogen air mixtures flowing in ducts. Characterize ignition versus Reynolds number, spark gap, and ignition energy. Compare results with real-world ignition sources.

- Task C - Survey manufacturers of electrolyzers and fuel cells to determine any special grounding needs for appliances used in residential garages.

- Task D - Survey manufacturers of portable fuel cells to determine what hazards may result from electrical shorts.

Project Safety Slide

- All testing is done under the direct supervision of Drs. Michael and Matthew Swain.
- Additional personnel are graduate students that are thoroughly briefed in their responsibilities.
- Only graduate students who have worked with Dr. Swain in the Internal Combustion Engines Lab for at least a year are allowed to assist in the Codes and Standards Analysis work.
- As is shown by this work effort, it is not as easy to ignite lean hydrogen-air mixtures as is commonly believed.

Project Timeline

Table 1 – Milestones

Month	1	2	3	4	5	6	7	8	9	10	11	12
Task A	Analysis of Lean Limit of Combustion for Gases Surrounding Hydrogen Leaks											Final Write Up
Task B				Analysis of Lean Limit of Combustion in ducts								Final Write Up
Task C		Survey of Grounding Needs				Analysis						Final Write Up
Task D							Survey of Electrical Short Hazards				Analysis	Final Write Up

Milestones:

End of 5th month: Complete survey of Grounding Needs (Task C-1)

End of 6th month: Complete analysis of Grounding Needs (Task C-2)

End of 8th month: Complete analysis of Lean Limit of Combustion for Gases Surrounding Hydrogen Leaks (Task A-1)

End of 10th month: Complete survey of Electrical Short Hazards (Task D-1)

End of 11th month: Complete analysis of Electrical Short Hazards (Task D-2)

Complete analysis of Lean Limit of Combustion in ducts (Task B-1)

End of 12th month: Complete Final Report

Technical Accomplishments/Progress

- Task A - Demonstrated that hydrogen air plumes are not ignitable at locations where 4.0% hydrogen exists, horizontally away from the leak. For a hydrogen leak at Mach 0.10 the distance from the leak to the ignition site must be at or below 75% of the maximum distance to 4%. For Mach 0.20 the value is 57%.

Technical Accomplishments/Progress

- Task B - Demonstrated that lean mixtures of hydrogen and air are not necessarily easily ignited by common ignition sources. This is due to quenching of the flame kernel by the electrodes producing the arc. Ignitability at the wall of the duct was found to be a strong function of spark gap size and a weak function of Reynolds number and ignition energy.

Technical Accomplishments/Progress

- Task C - Special grounding may be necessary when fuel cells are used to provide electricity independently from the residential garage electrical system.

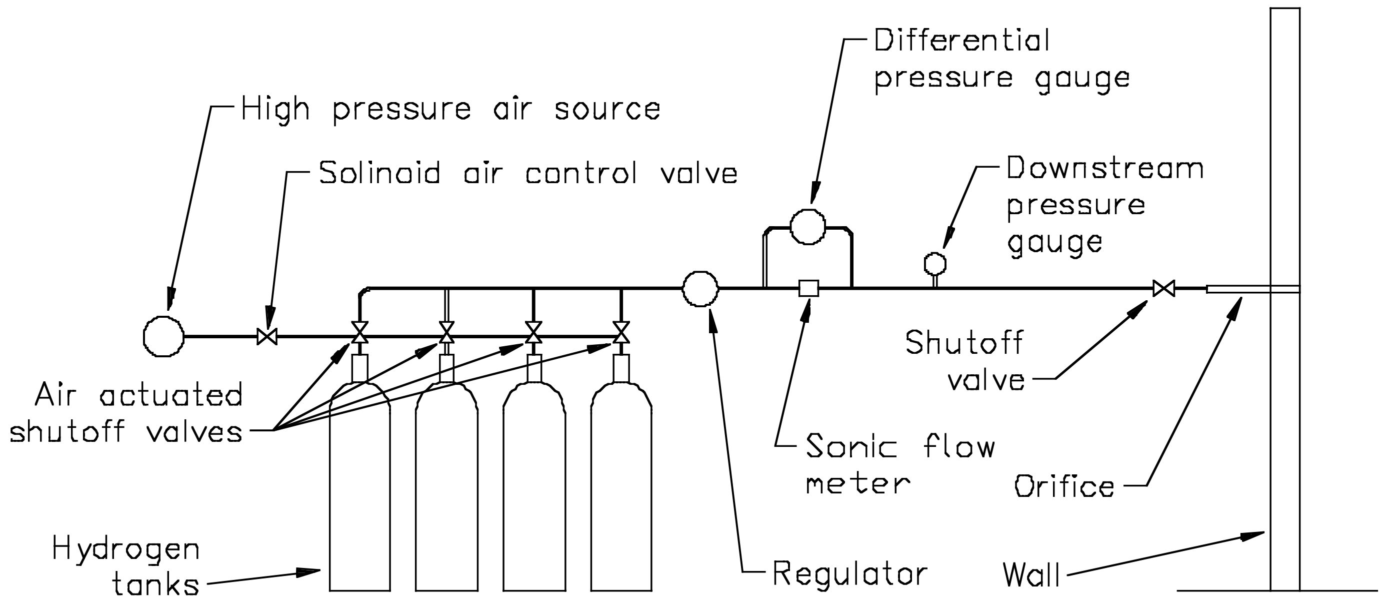
- Task D - All fuel cells surveyed provided electrical short protection.

Technical Accomplishments/Progress

Commonly quoted properties of hydrogen

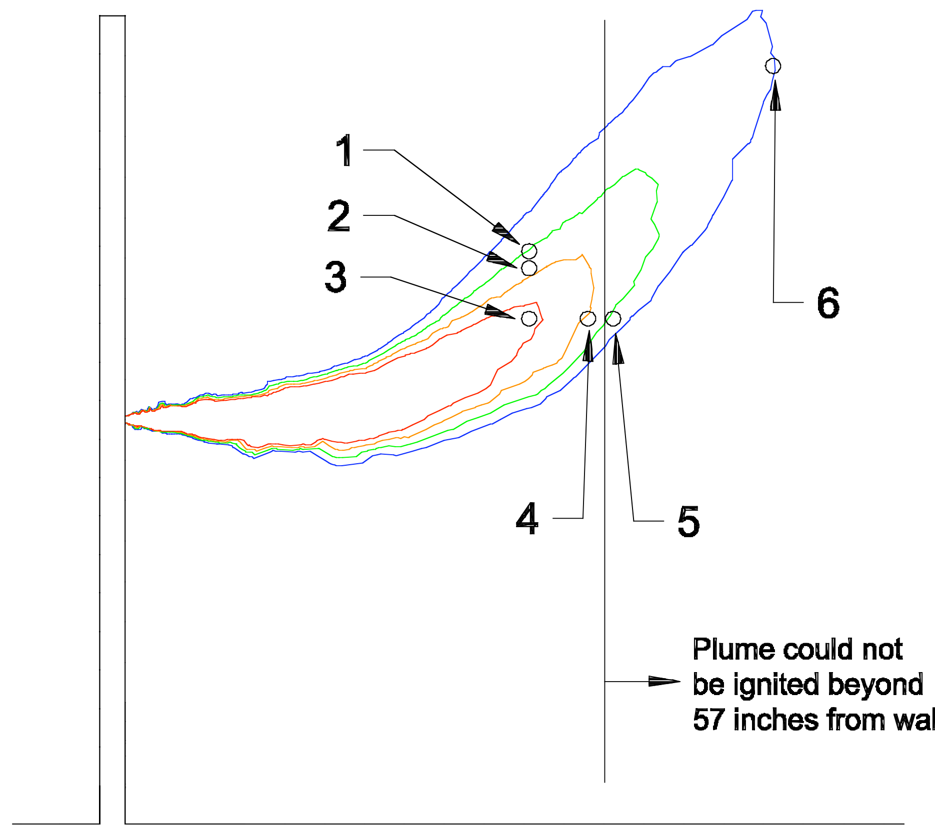
- Lean limit of combustion 4.0%
- Minimum ignition energy 0.02 mJ
- Minimum quench distance 0.065 cm (0.026 inches)

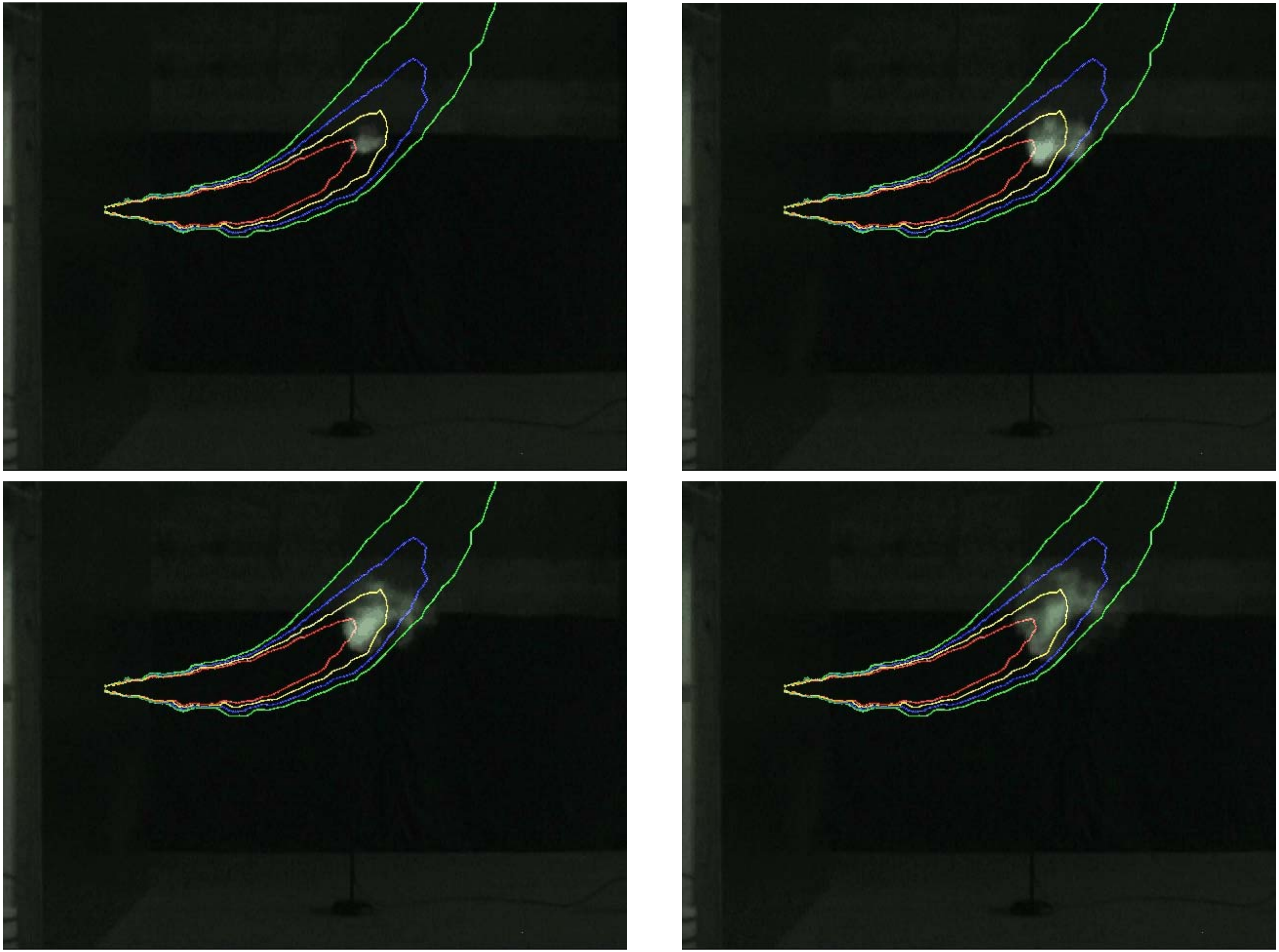
Plume Test Apparatus

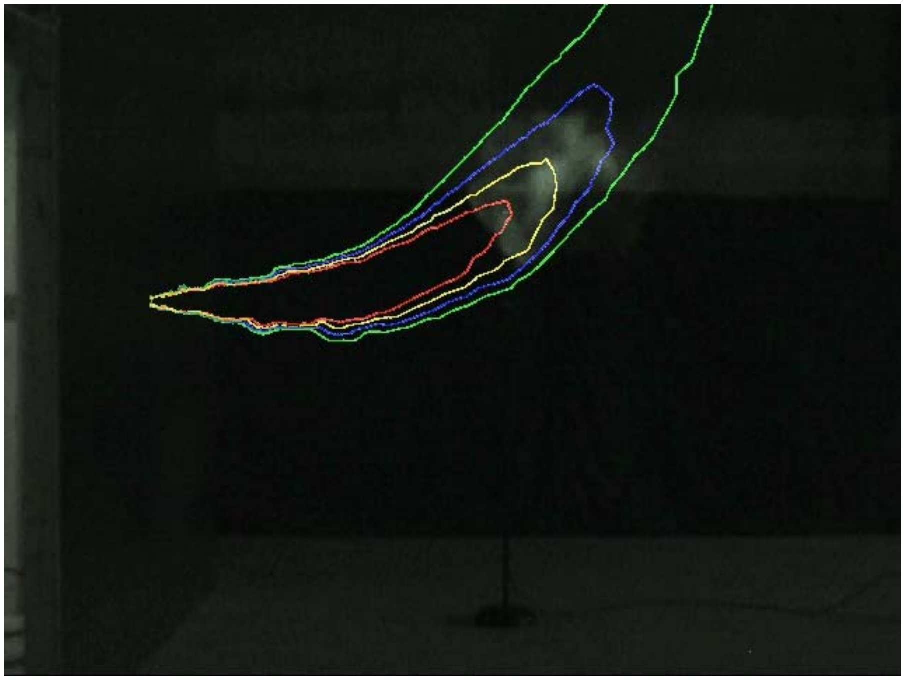


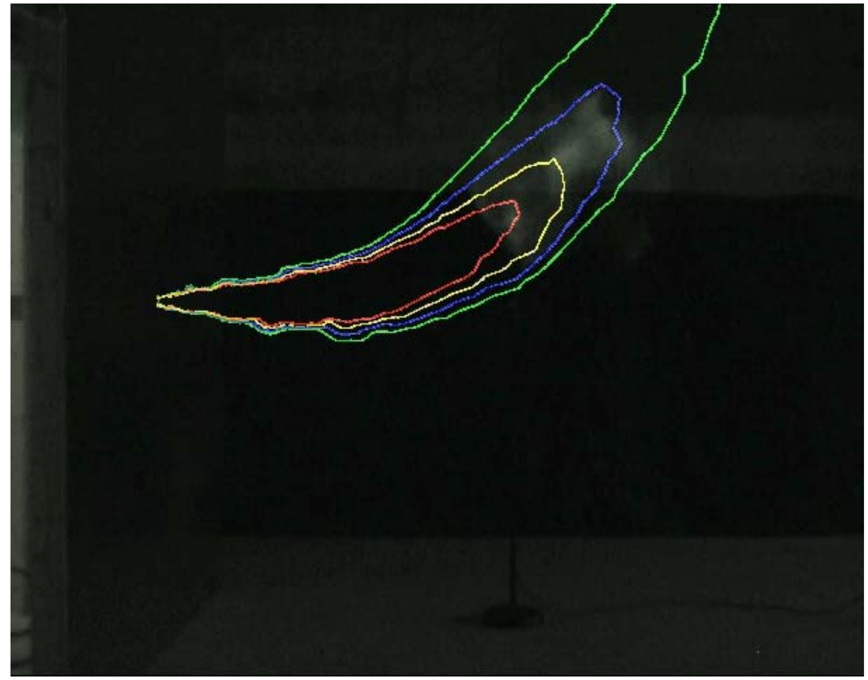
Technical Accomplishments/Progress

	CFD Model @ 45 seconds Hydrogen %	CFD Model @ 60 seconds Hydrogen %	Experimental Data Hydrogen %
Point 1	6.0	5.6	5.0-5.9
Point 2	7.2	6.8	5.6-7.0
Point 3	10.4	10.2	9.4-10.8
Point 4	7.8	7.7	8.1-9.4
Point 5	5.6	5.5	5.6-6.6
Point 6	3.7	4.3	3.5-4.6



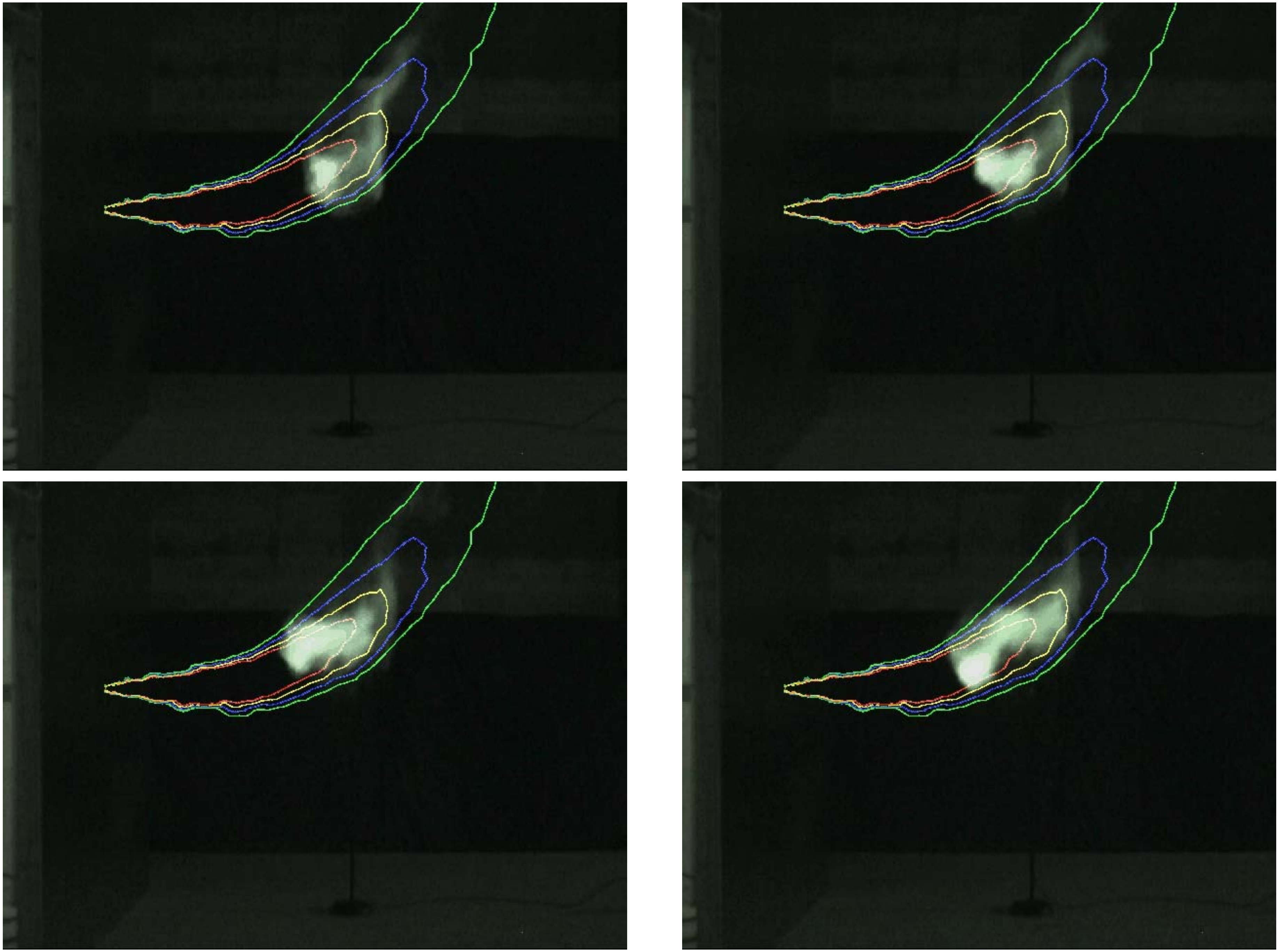


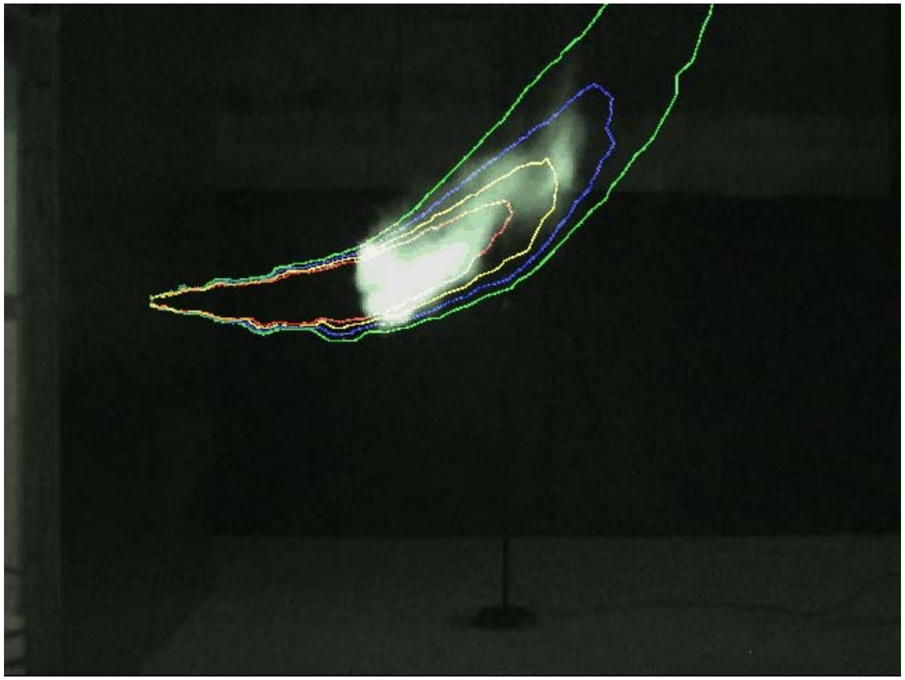


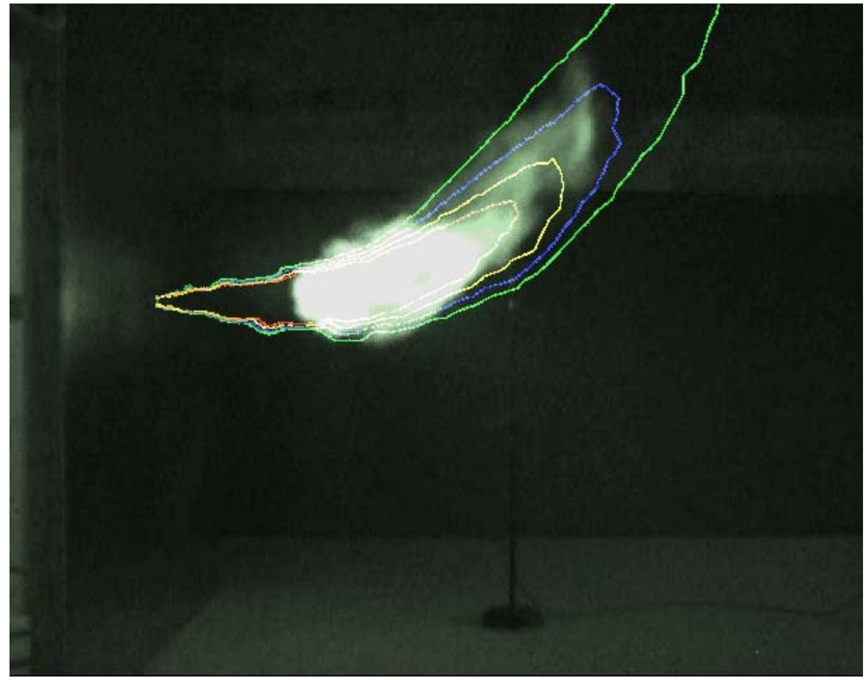


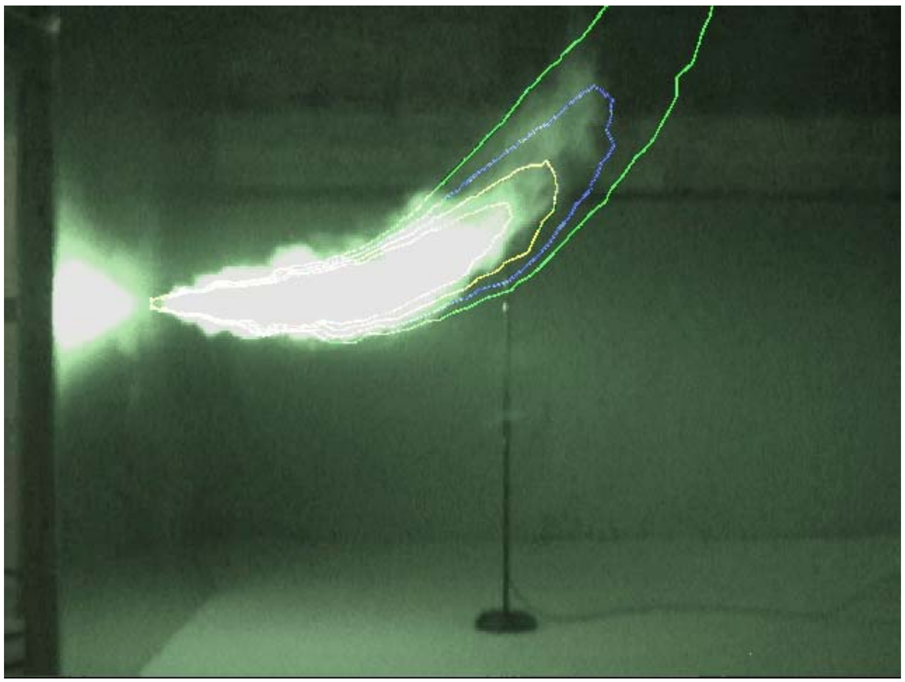
Example of failed ignition at a location that contained 10% hydrogen

- Hydrogen flow rate 20 SCFM
- Orifice size 0.372 inches in diameter
- Leak duration 45 seconds



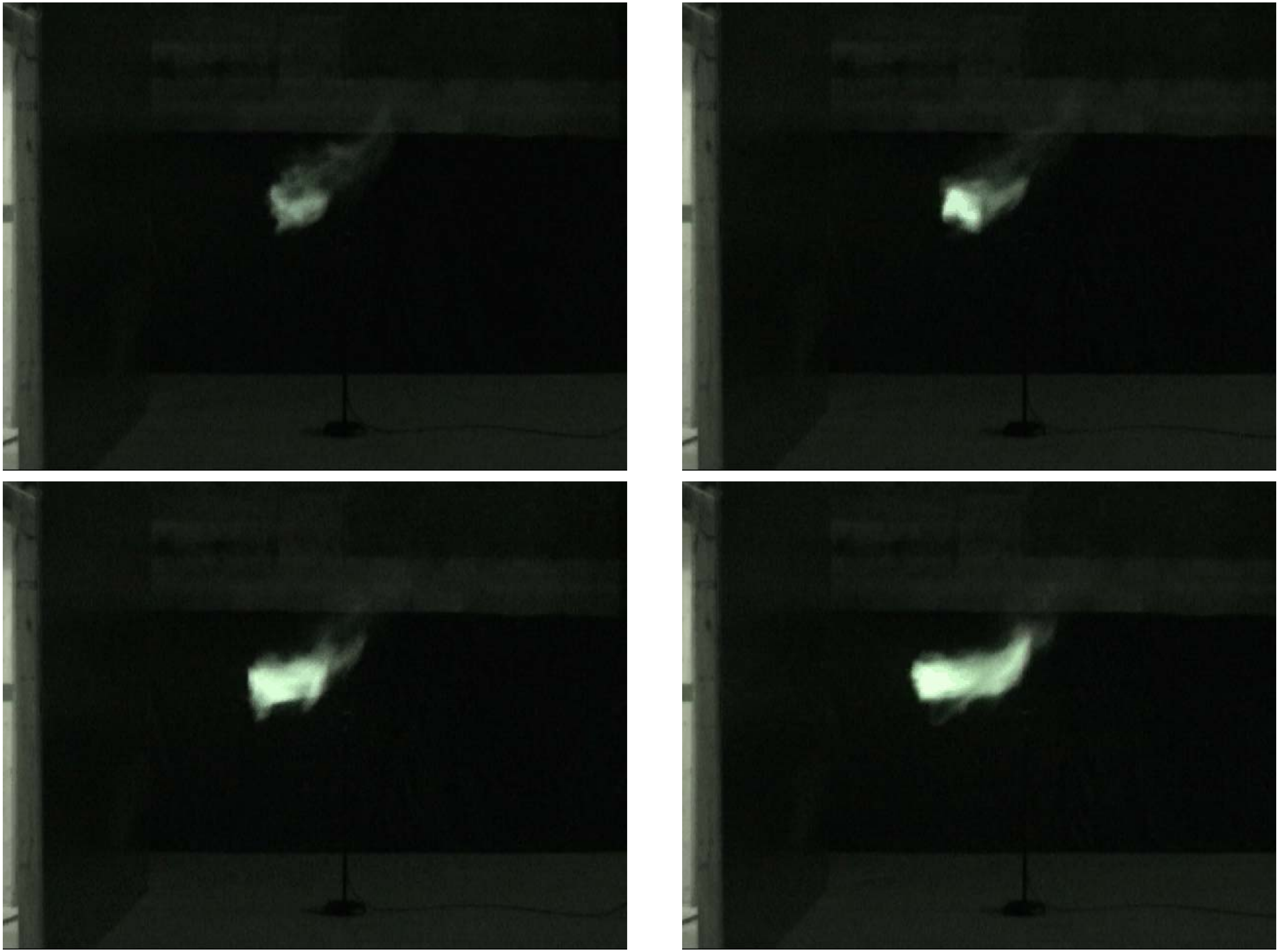


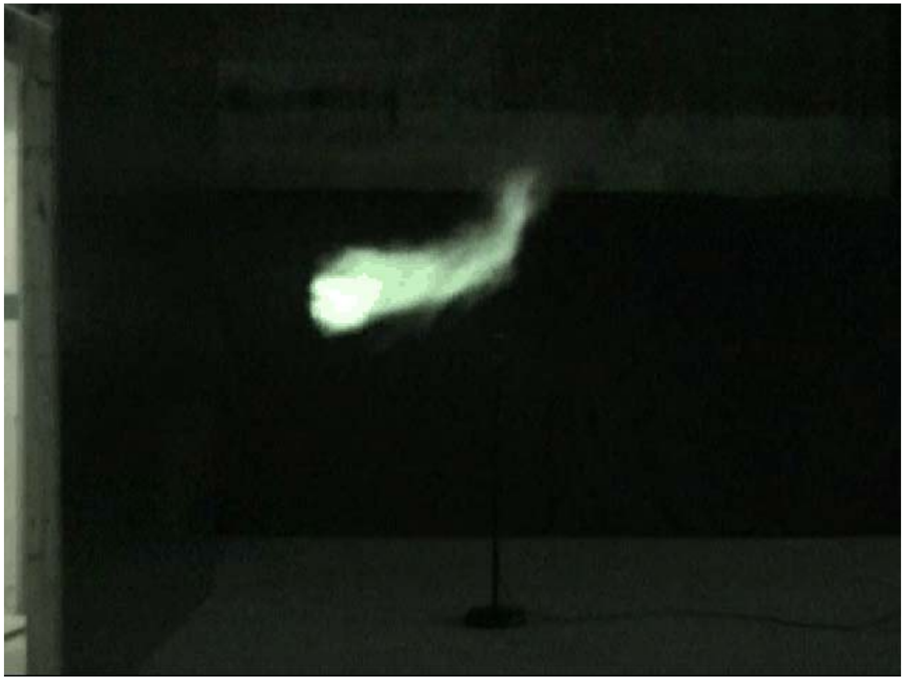


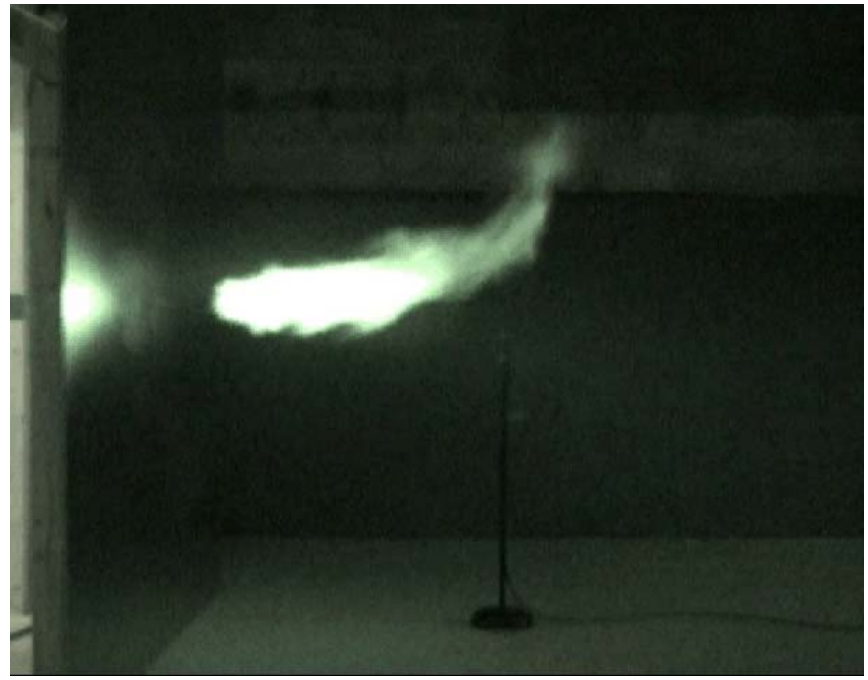


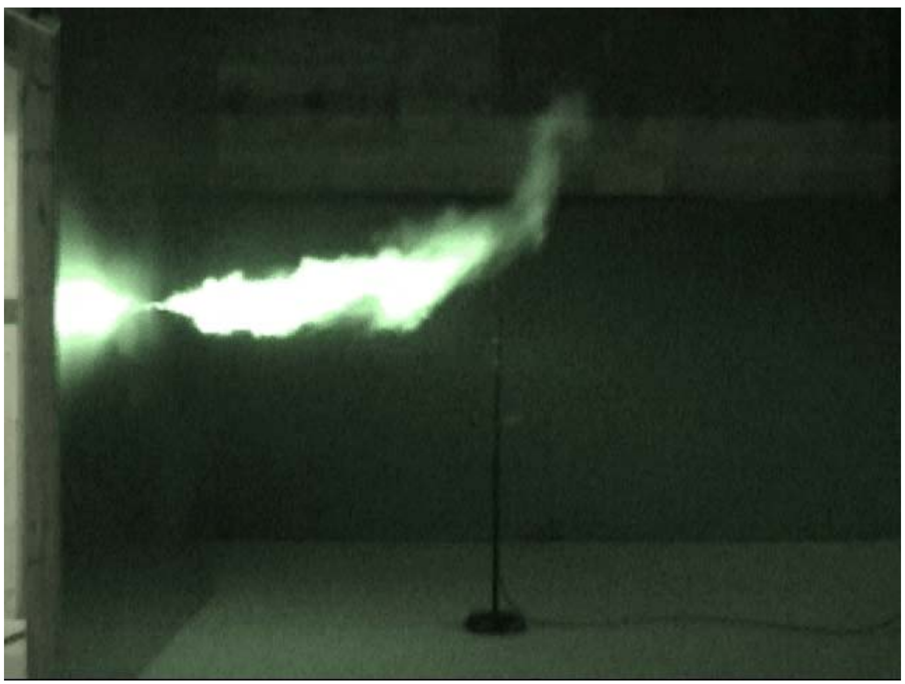
Example of successful ignition attempt at a location that contained 10% hydrogen

- Hydrogen flow rate 20 SCFM
- Orifice size 0.372 inches in diameter
- Leak duration 45 seconds



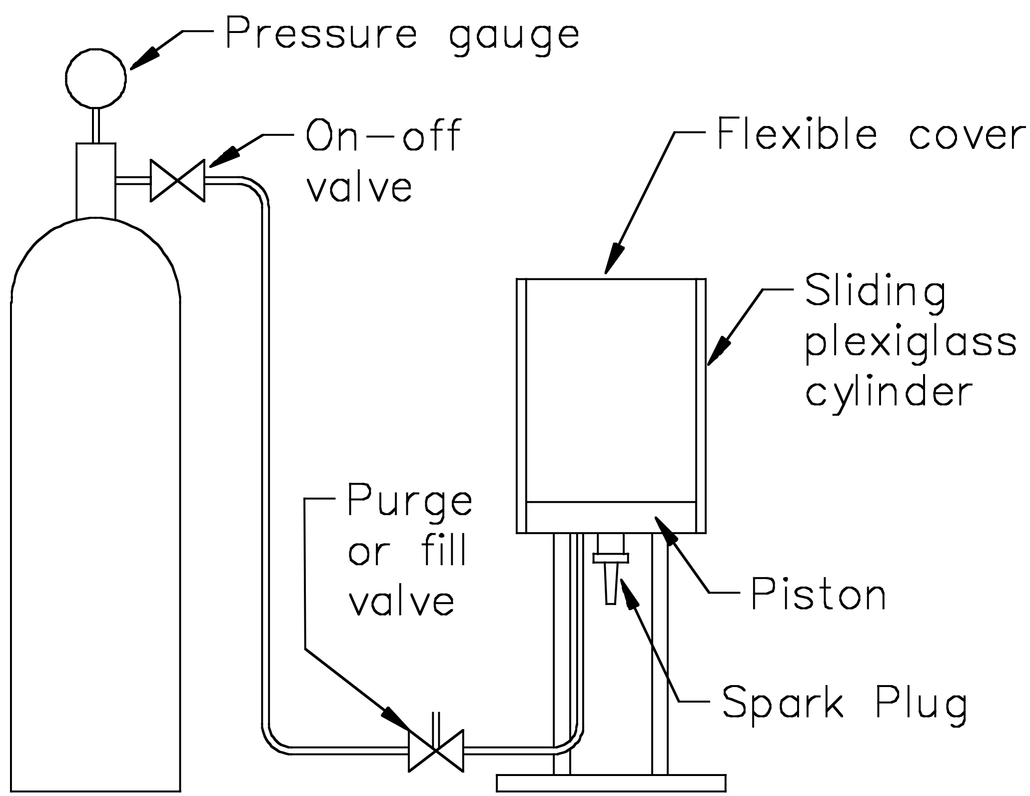






Example of successful ignition attempt at a location that contained 10% hydrogen

- Hydrogen flow rate 20 SCFM
- Orifice size 0.263 inches in diameter
- Leak duration 43 seconds



Apparatus for quiescent homogeneous hydrogen-air ignition tests

- Gap of 0.020 inch produced no ignitions of 7% hydrogen but gap of 0.060 inch produced ignitions every time

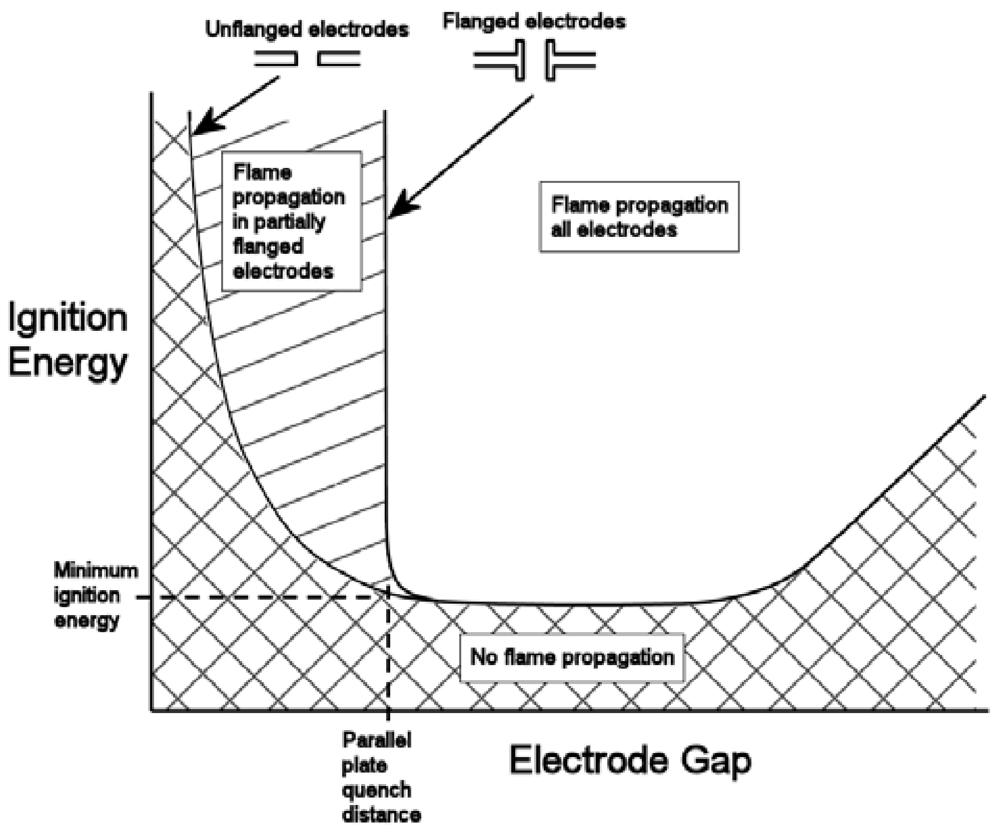
Ignition of 5% hydrogen after 3rd attempt with gap of 0.126 inches

Technical Accomplishments/Progress

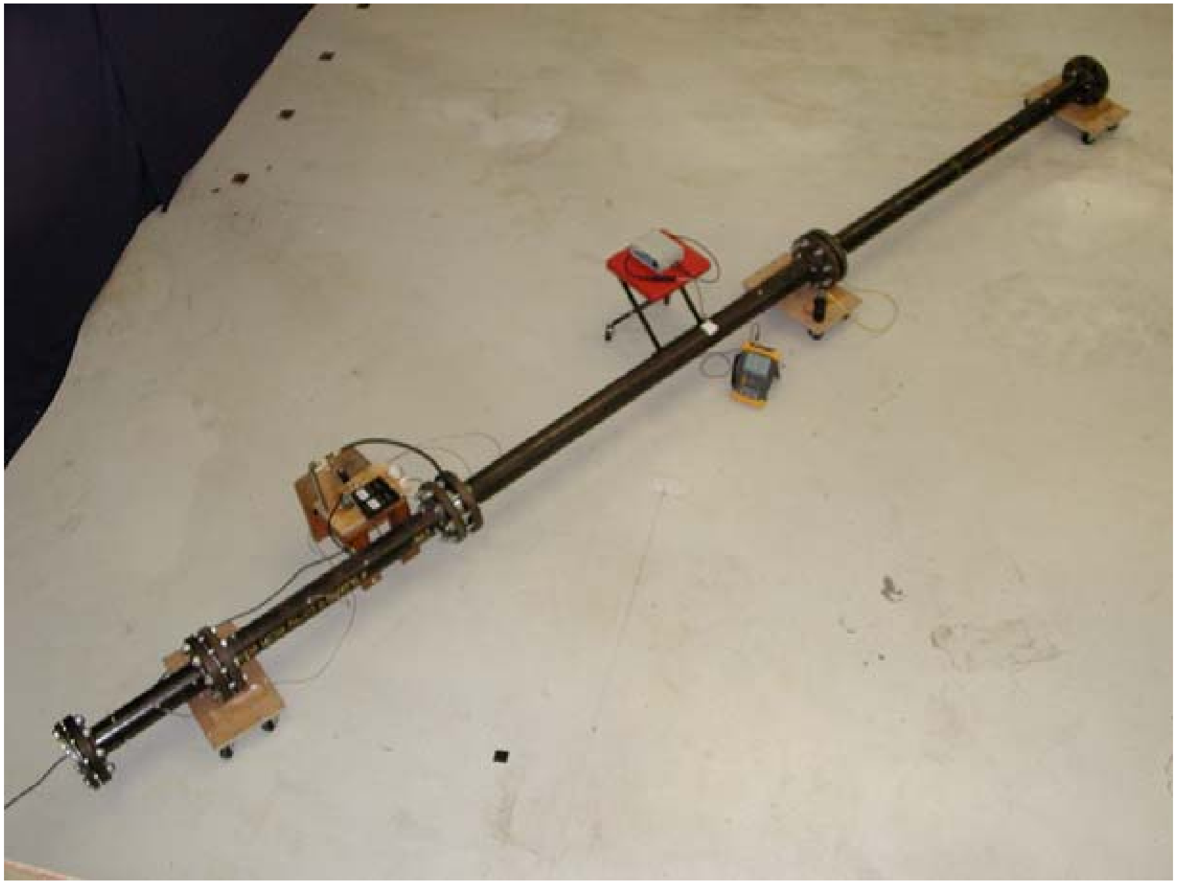
Hydrogen concentration in air	Parallel plate quenching distance cm (in.)	Minimum ignition energy (mJ)
4%	1.32 (0.52)	10.0
5%	0.69 (0.27)	3.0
6%	0.39 (0.15)	1.0
7%	0.28 (0.11)	0.56
8%	0.22 (0.09)	0.33
9%	0.18 (0.07)	0.21
10%	0.16 (0.06)	0.15

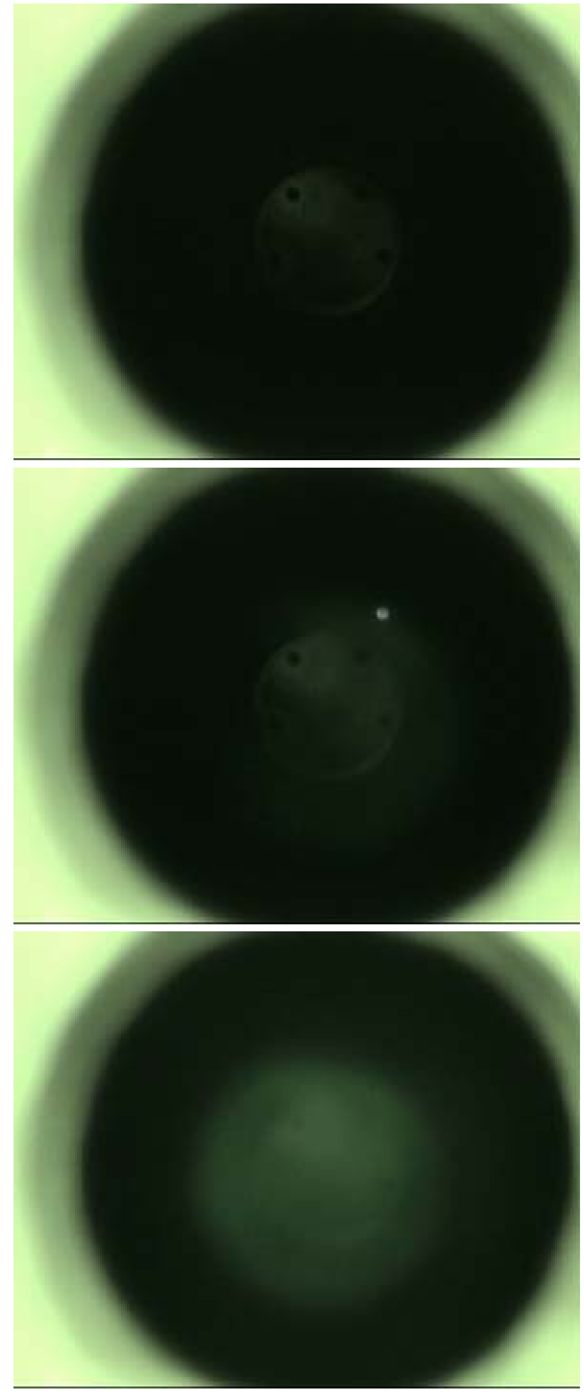
Accepted values for parallel plate quenching distance and minimum ignition energy for lean mixtures of hydrogen and air

Technical Accomplishments/Progress

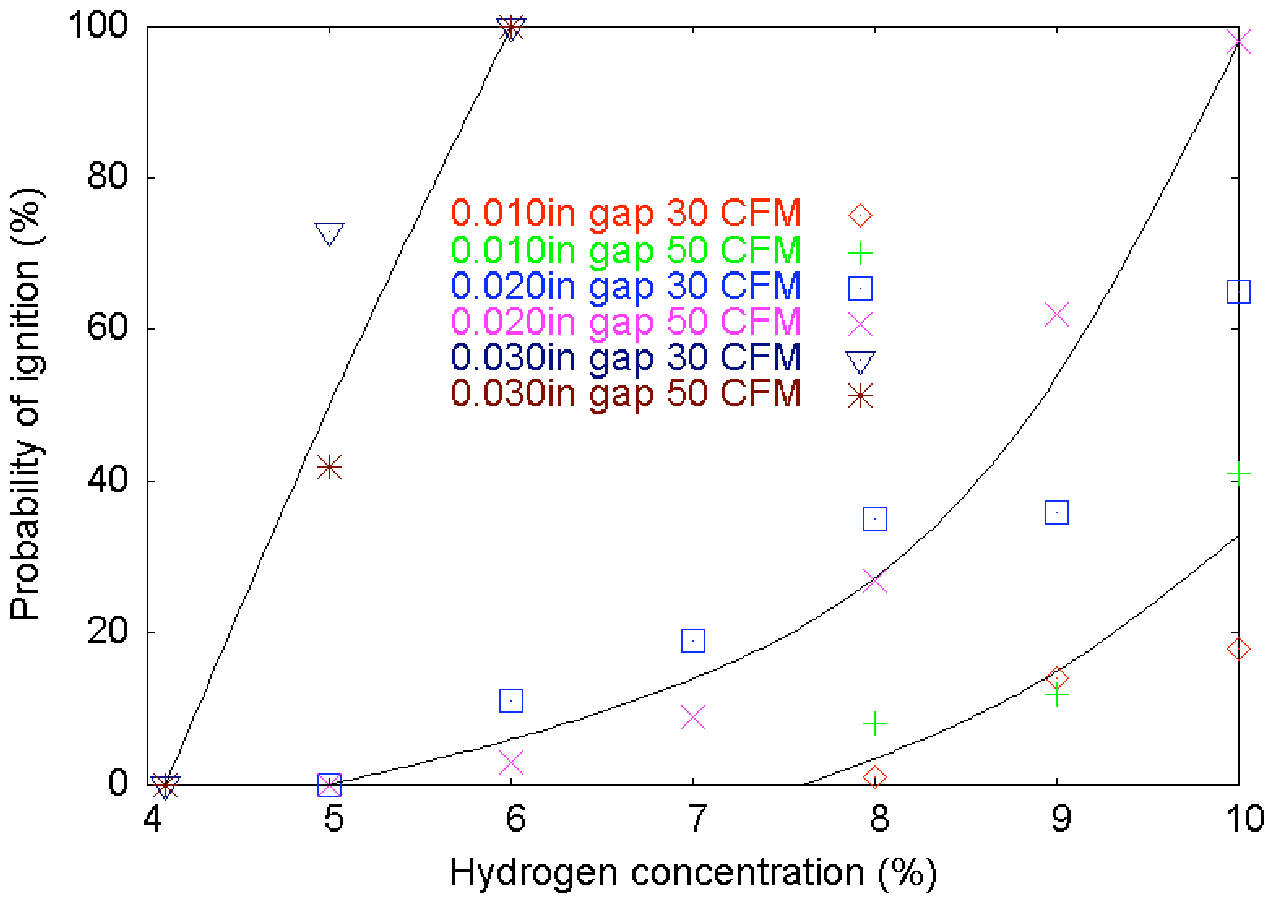


Accepted behavior of flame propagation as a function of ignition energy, electrode gap size and gap geometry





Experimental apparatus used to test ignition in ducts. The three photos shown at right are a view into the exit of the duct during an ignition of 8% hydrogen. Top is prior to ignition. Note the point of light in the middle photo from the arc. The bottom photo shows the flame propagating toward the exit.

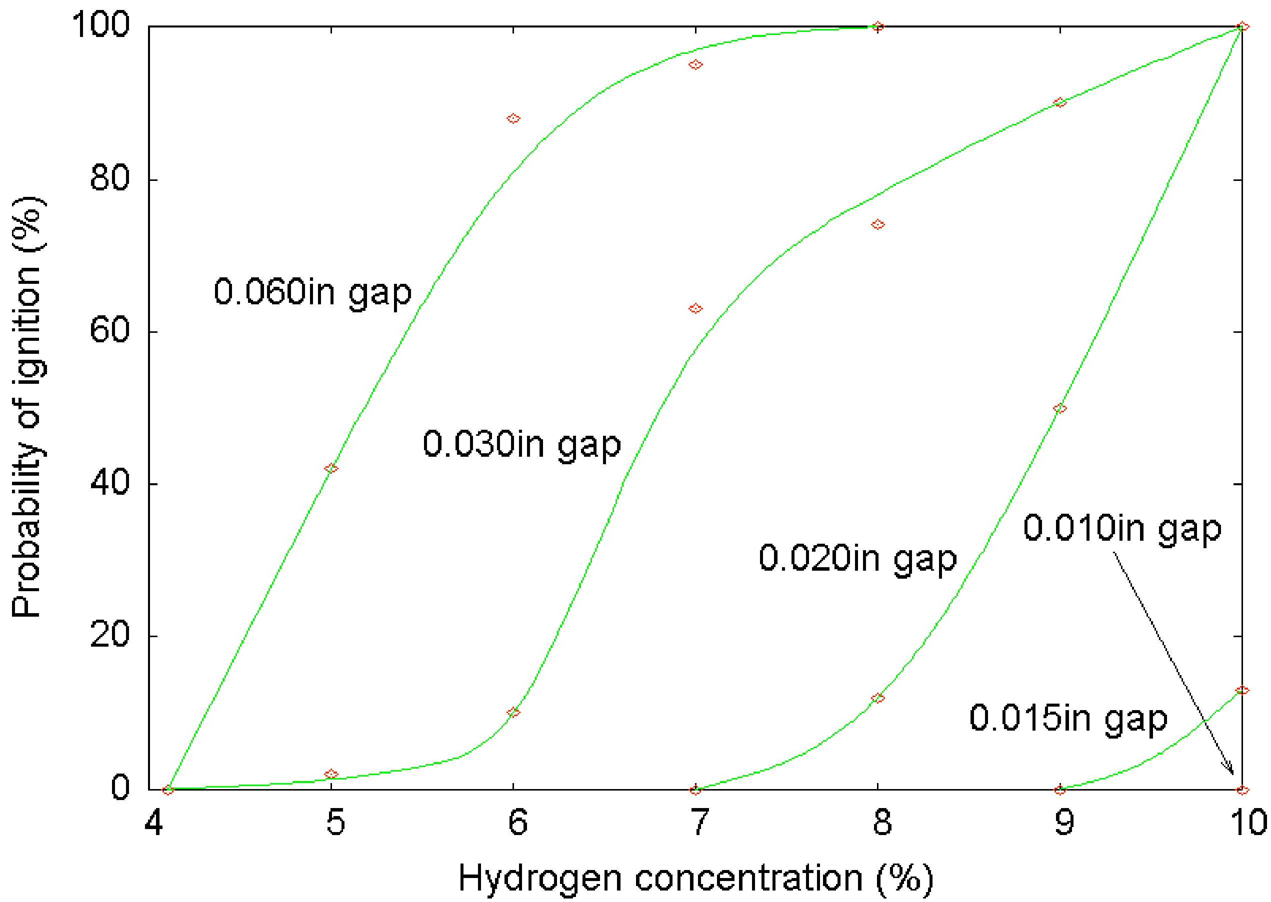


Experimentally determined probability of ignition versus hydrogen concentration for various spark gaps sizes at wall of duct.

•Ignition energy 205 mJ

•Shows weak dependency on Reynolds Number

•Shows strong dependency on spark gap size

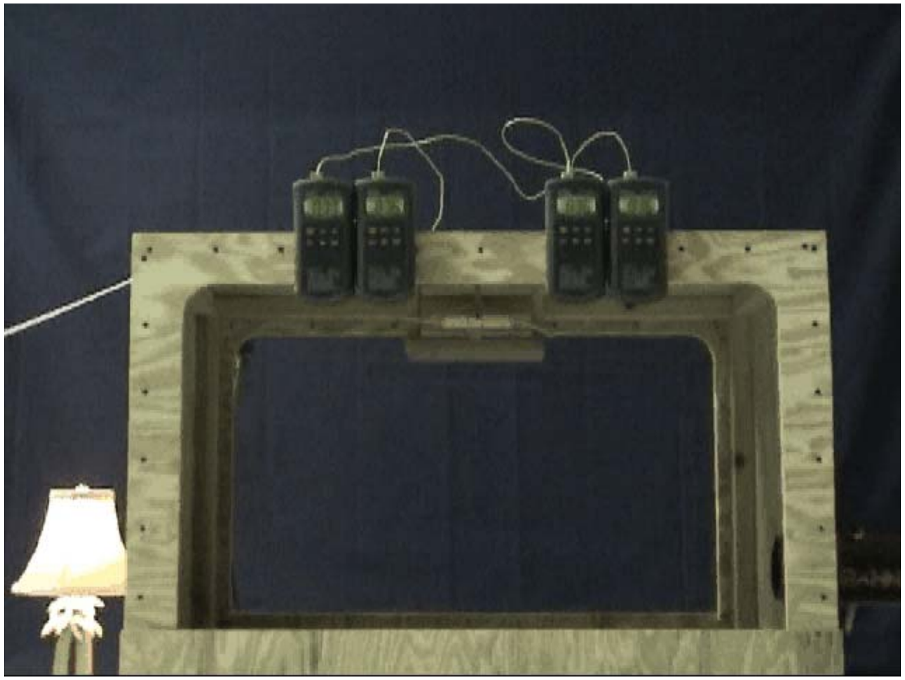


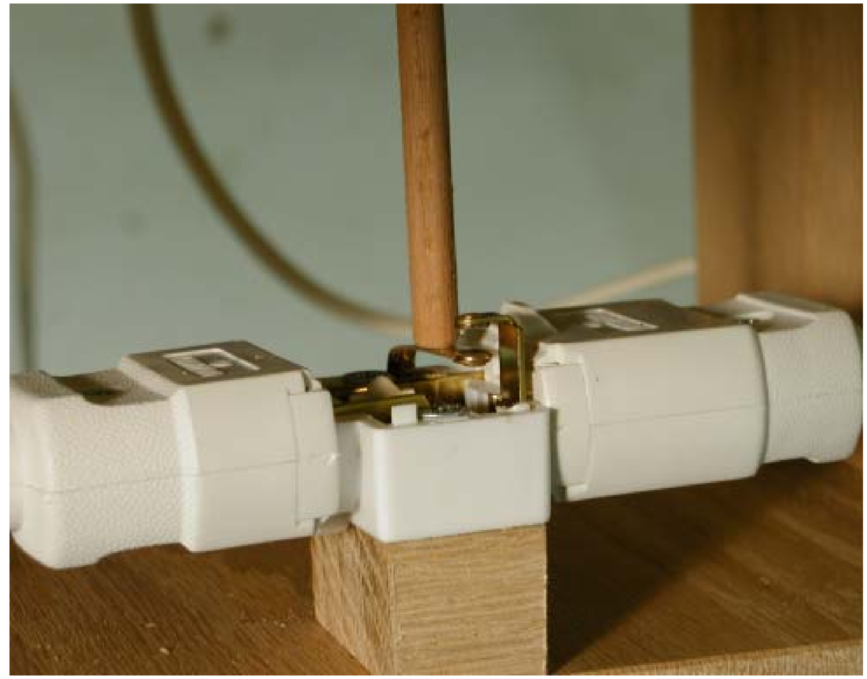
Experimentally determined probability of ignition versus hydrogen concentration for various spark gaps sizes, 0.4 inches from wall of duct.

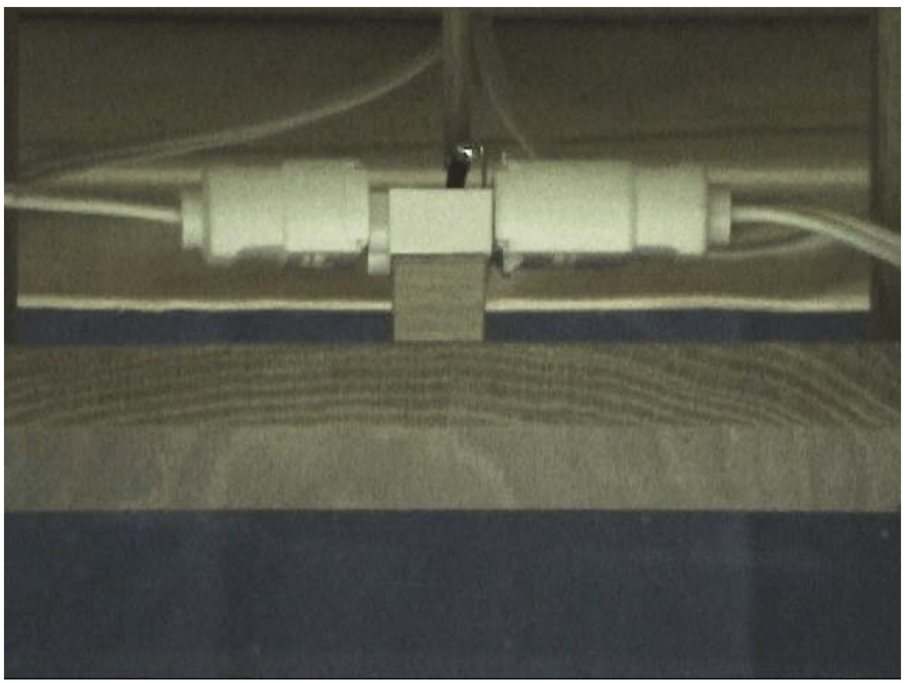
•Ignition energy varied between 51 mJ and 205 mJ

•Shows weak dependency on ignition energy

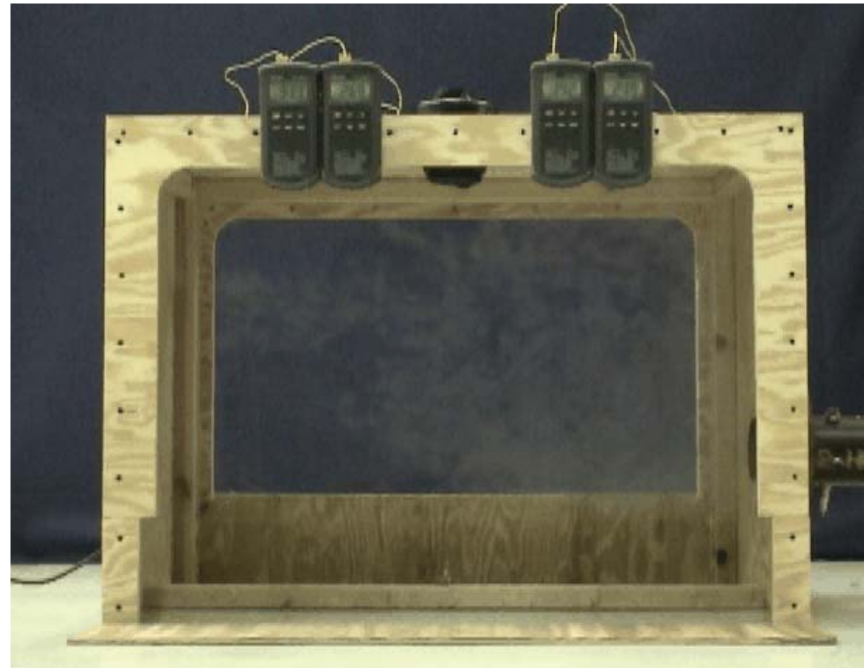
•Shows strong dependency on spark gap size



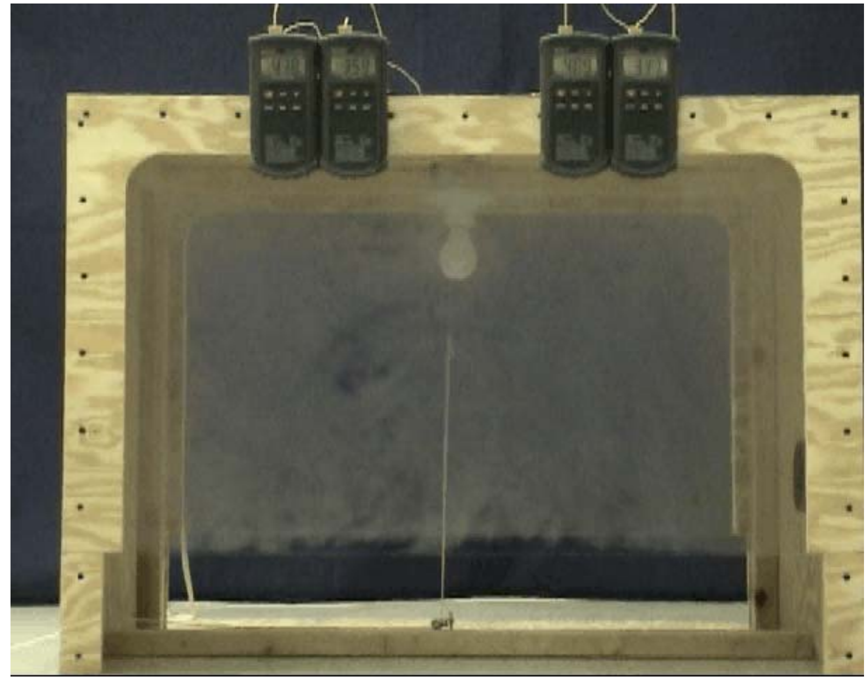




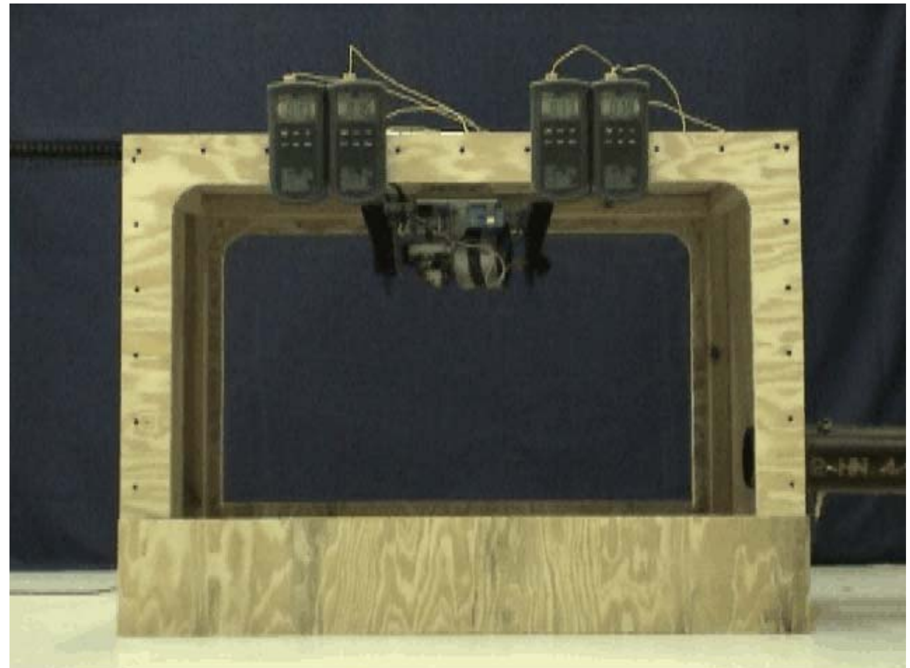
The contacts in a common light switch would not ignite 4% through 10% hydrogen. 78 attempts were made to ignite 10% hydrogen. Photo above shows contact electrodes fully open. Photo to left shows the contact electrodes during a test (note the arc in the open gap).



A 10 year old 1.25 HP shop vac motor was initially able to ignite 7% hydrogen. Ignition produced a temperature rise at the thermocouples, the pressure relief panels at the bottom to drop (as shown) and condensation on the Plexiglas. Disassembly of the motor and further scuffing of the brushes allowed ignition of 6% hydrogen.



A ceiling light with a pull chain was able to ignite 8% hydrogen. The light switch utilizes a rotating bar to make electrical contact. This inherently produces less quenching than the flat disk type contacts. Ignition occurred on the 7th attempt.



A new residential _ HP garage door opener would not ignite 4%-10% hydrogen concentrations. The motor was operated for one minute at each concentration. Note in the photo on the right that the motor assembly cover was removed to assure access for the hydrogen-air mixture.

Interactions and Collaborations

- A separate contract with Sandia National Labs allowed us to develop CFD modeling techniques, utilizing helium rather than hydrogen, which were directly applicable to this work.

Responses to Previous Year Reviewers' Comments

- Significant questions/criticisms : "Within the framework of Codes and Standards, bring in fire marshals and non-technical people into the design of experiments"
  - We asked local fireman, students, and their parents whether they thought tests of electrical appliances, to show the relationship between our theory derived from duct experiments and real-world ignition sources, would be useful. There was a strong positive response.

Responses to Previous Year Reviewers' Comments

- Weaknesses: "None specified"

Future Work

- Make 1:45 hour presentation of research results at Fuel Cell Summit VIII, June 15-17, 2004, Miami, Florida.